Implementation of Noninvasive Flow Velocimetry through Monte Carlo Simulation

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Abstract- **One of the most important mechanisms for maintaining the life of human beings is the human circulatory system. This research focuses on a non-invasive technique that maintains high resolution and high precision of measuring photon in the blood stream. We hope to obtain important biomedical parameters valuable for pathological diagnosis.**

In phase I, a non-invasive optical flow velocimetry is implemented for detecting the human circulatory system under the skin surface. The source of the incidence photon is He-Ne laser. The signal is transmitted and detected via a Y-type optical fiber. Optical heterodyning is used to measure the frequency difference between the reflection wave and the original incidence laser wave. Then numerical simulation using Monte Carlo was used in the analysis to verify the result.

In phase II, after a velocimetry specification was decided, it was modeled, tested and verified using Monte Carlo simulation. Then the apparatus were set up as directed in the model. The performance of this velocimetry is satisfactory and acceptable. This method of implementing a velocimetry is simple, convenience and fast. Thus, no prior clinical experiment is need. Moreover, the best reading for the reflected wave is 45° ±2.35 ° . This is a real-time and continuous detecting blood flow velocimetry. We find that this is a reliable tool for doctors when doing clinical diagnosis.

Key words: clinical detection, circulatory system, He-Ne laser, optical heterodyning.

I. INTRODUCTION

Noninvasive optical electrical detection techniques [1,2] with high resolution and high precision have become the important aim of many research institutes. However researchers are especially interest in minimizing the dimension of clinical detection devices. To attain this goal, at present the use of optical fiber has become one of the most important and indispensable methods. For example, we can use non-invasive optical oximetry [3] and fiber-optic fluorometer [4] to analyze the human organizations.

Blood flow velocity is one of the important parameters of human circulatory system [5]. In recent year there have been many indirect methods proposed by many specialists to detect this parameter via skin surface. However, all these methods do not provide continuous detection. This will result in some restriction for their usage in some special applications. In recent research, coherent monochromatic laser light is used to incident the skin surface directly. This provides clinic research on blood flow velocity via the Doppler effect. This method can serve as a continuous non-invasive direct detection technique.

The earliest application of Doppler effect to detect blood flow velocity is published by Riva [6] and his group in the study of blood flow of Rabbits' retina capillary in 1972. In 1974, Tanaka's group [7] extends it to the experiment of human body. One year later they use optical fiber to detect blood flow velocity. In 1978, the first detection system of blood flow velocity on skin surface using laser Doppler effect is implemented by Watkin and Holloway [8]. There are many papers [9-10] related to the performance and the associate applications on clinical detection and diagnosis.

However, there is little or highly any research on continuous detection. Moreover setting up the optical velocimetry is difficult and usually need bioexperiment prior to set up.

To realize this aim, In phase I, we implement the blood flow velocimetry with fiber, laser fiber driver, and signal amplifier. Laser Doppler effect is used as a guideline. Besides this, numerical simulation using Monte Carlo is used in the analysis and processing. In phase II, we model a velocimetry specification using a Monte Carlo model. The model is tested and verified. Then we set up the hardware as directed in the model. By doing so, we hope to learn more about the associate mechanism on circulatory system of heart and body surface. Besides constructing a real-time and continuous detection tool, our main research aim is to find a more effective and reliable tool to help doctors to do clinical diagnosis.

II. METHODOLOGY

When we use coherent laser light to focus on some moving object, the light wave of reflection will change its frequency when the relative location and the velocity of this moving object changes. This relation is as follows:

$$F = (1/2 \pi) \times (K_s - K_i) \times V \quad (1)$$

K_s and K_i are the propagation vectors of the scatter beam and incident laser beam respectively [11]. V is the velocity of the moving object and f is the frequency change of the reflective wave. Fig. 1 shows the optical setup for the two-fiber laser Doppler anemoment. The polarized He-Ne laser beam is divided into incident and reference beams by the 50/50 polarized beam splitter (BS). The reference light is coupled into photodiode though another beam splitter. The incident light is passed into the transmission fiber via the fiber-optic coupler toward the catheter and through the skin surface into the red blood cell(RBC). Based on Doppler effect, the scatter light frequency shifts by df (f+df) and is transmitted via the receiving fiber into the spectrum analyzer. Optical heterodyning method is used to obtain the blood flow velocity.

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Abstract

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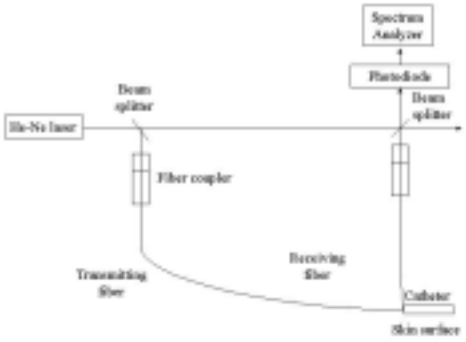

Fig. 1 Schematic diagram of the two-fiber Laser Doppler Anemoment

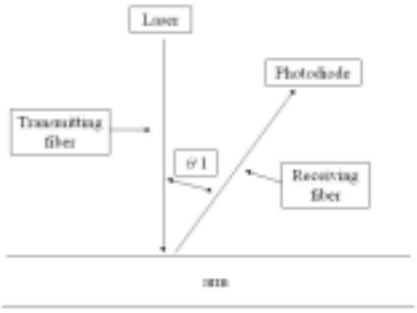

Fig. 2 Sectioned view of the fiber catheter

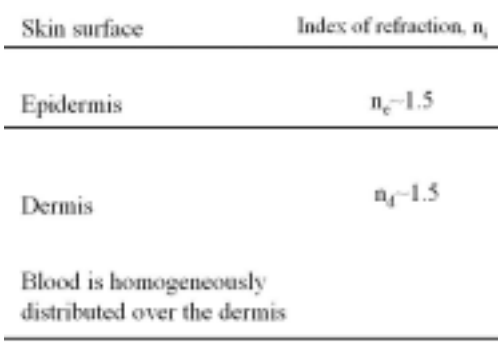

Fig. 3 Schematic model of skin with plane parallel epidermal and dermal layers. Each layer is homogeneous and has isotropic physical properties.

Fig. 2 is the sectioned view of the fiber catheter. In this figure, the transmission fiber is perpendicular to the arm and the receive fiber is at an angle θ with the arm. Please note that the catheter does not directly contact to the arm. Consequently, there are three parameters in this optical system namely $\triangle f, \theta$ and the distance form catheter to the arm d.

A schematic model of the skin consisting of epidermis and dermis as two plane parallel layers with isotropic physical properties is shown fig.3. From this figure, we can have a roughly glimpse of how the laser beam propagate through the skin[12]. We assume that the laser beam pierce though the skin, and induce the scattered light. As we do not know the exact path taken by the laser beam when it propagate though the skin and the direction of the scattered light, a numerical method using Monte Carlo simulation may solve these problems.

Monte Carlo method is also called random process method. This operation shows that the recursive formula

$$r_{i+1}=(\alpha r_i+\beta)\text{MOD } N \qquad (2)$$

generates uniformly distributed random number between zero and N-1, with $N=2^{20}=1{,}048{,}576$, $\alpha=1909$, and $\beta=221{,}571$[13]. the MOD operation is defined as the integer remainder of $(\alpha r_i+\beta)/N$. the period of the pseudorandom sequence is $N=2^{20}=1{,}048{,}576$, and the limits on the seed are $1 \leqq r_o < N$.

If the results of the simulation and our experiment are near identical, we can use the result of the simulation to build the system without performance prior bioexperiment. We use one way analysis of variance (one way ANOVA) and F test [14] to analyze and verify our results.

III. Results

These are three main parameters namely $\triangle f$ 、θ and d in the optical system. In the measurement we discovered that $\triangle f$ is nearly unchanged. The transducer must adhere to the skin surface to obtain good result. Thus d must be keep to a minimum. Then we focus on changes in θ angle. We took reading from 30° to 60° at a step increment of 5°. For each step 25 values were taken at 5 seconds interval. Thus a total of 125 seconds duration was used in each step. This undertaking is to ensure an unbiased in average reading. The measured value of each data is from peak to valley and the flux speed is shown in mV. The whole experiment was repeated with 4 different healthy subjects. Thus a total of 100 values were recorded for each degree. The result was shown in fig. 4. The result showed that there is maximum value at 45°.

Table I shows the mean values of these four experiments. Statistics package, SAS was used in numerical analysis (in Table II) ANOVA shows that there is significant difference between angles. This is because the F value reaches the statistic threshold.

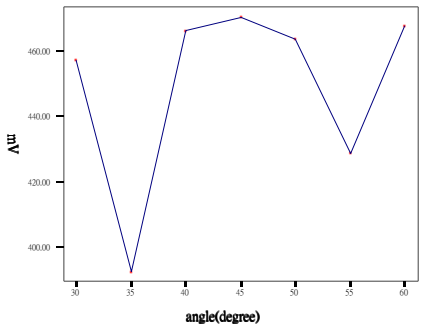

Fig. 4 Line shows mean

TABLE I
The data shows the mean of the result (mV)

Angle(degree)	30	35	40	45	50	55	60
1st experiment	707.46	390.5	569.58	446.63	516.88	622.13	519.92
2nd experiment	286.08	495.67	377.46	318.58	316.63	409.58	538.5
3rd experiment	498.41	283.93	640.52	475.52	647.85	462.52	421.7
4th experiment	337	413.08	263.76	632.84	354.2	224.52	399.76

TABLE II
ANOVA for Clinical Experiment

	Sum of Squares	df	Mean Square	F value
Treatment	497316.437	6	82886.073	2.239
Error	25658973.67	693	37025.936	
Total	26156290.11	699		

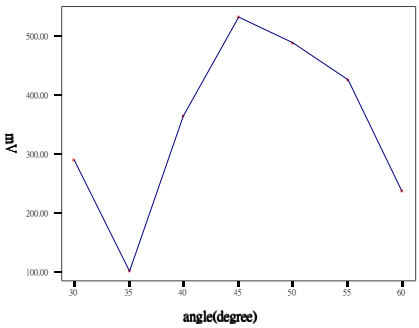

Fig.5 Line shows mean for Monte Carlo simulation

TABLE III
ANOVA result of Monte Carlo Simulation

	Sum of Squares	df	Mean Square	F value
Treatment	13624558.477	6	2270759.746	56.741
Error	2773818.954	693	40019.941	
Total	41358377.430	699		

In Monte Carlo simulation, we took reading from 30° to 60° at a step increment of 5°. As above, this experiment was repeated with 4 healthy subjects. Thus, a total of 100 values were recorded for each degree. This situation was the same as clinical experiment. The result was shown in fig. 5. The result showed that there is a maximum value at 45°.

The result of the computer simulation ANOVA shows that there is significant difference for certain angles. This is because the F value does not reach the statistic (see Table III).Therefore, the designer can decide any angle within $45^\circ \pm 2.35^\circ$. This result is the same as the result with prior clinical experiment.

IV. Discussion

A paper in the Flow Meas. Instrum. [11] suggested that θ at 45° is used to set up their optical system. From our experiment, we notice that if the flow is greater, the amplitude is greater. To support this view, we covered our wrist with ice for two minutes before recording. We observed that the flux value decreases substantially.

V. Conclusion

The performance in implementing flow velovimetry using Monte Carlo method or usual practice is near identical. We can use the result of the simulation to build the system without conducting prior bioexperiment. Moreover, the best reading for θ is $45^\circ \pm 2.35^\circ$ .This is a real-time and continuous detecting blood flow velocimetry. We find that this is a reliable tool for doctors when doing clinical diagnosis.

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